MICHIGAN CONCRETE ASSOCIATION

HOT & COLD WEATHER CONCRETING PLUS CURING

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PDF handouts of slides: https://info.miconcrete.org/virtual-learning


Curing
Concrete

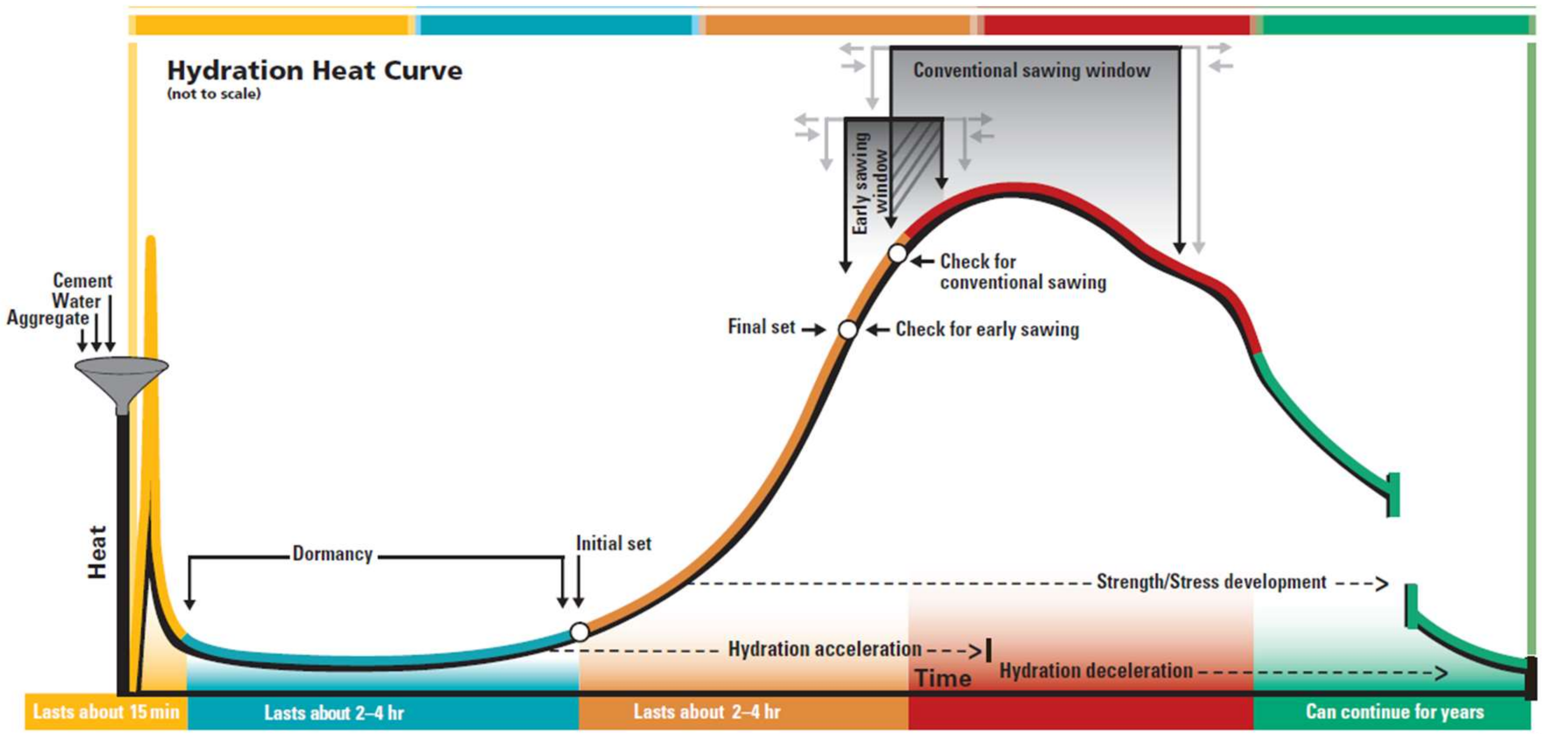
Defined

The action taken immediately following finishing to maintain moisture and temperature conditions (for a sufficient period of time) in freshly mixed concrete to allow hydration and pozzolanic reactions to proceed.

- proper curing prevents rapid water loss from the mixture and allows more thorough cement hydration

- temperature and moisture directly influence both early and long term concrete properties such as strength and durability

Heat of Hydration Curve



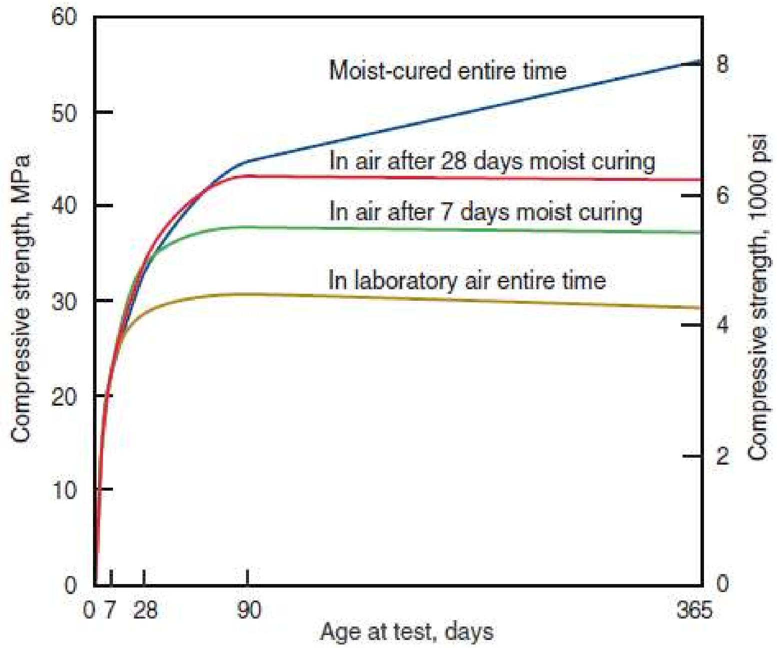
Curing

Properties impacted by curing:

1. durability - the resistance to freezing/thawing and deicing chemicals
2. strength - reductions up to 50% can occur
3. permeability - the ease at which water enters the concrete
4. abrasion resistance - dusting or flaking
5. volume stability - an increase in the number of cracks

Note: Exposed slab surfaces are particularly sensitive to curing as strength development and durability of the top surface of a slab can be significantly reduced when curing is neglected.

Moist Curing vs Compressive Strength



Curing Requirements

Duration: As long as possible, but a minimum of 3 days.

Begin immediately following finishing!

Temperature: 50-100°F (Do not confuse with curing cylinders!)

Moisture: Keep concrete saturated at **all** times.

(If curing is interrupted then resumed, hydration will be reactivated but the original strength potential will not be achieved.)

Reminder: Strength development (hydration) ceases after the internal relative humidity in the concrete drops below 80%.

Cure System

Too often it is the last thing on our minds

More critical with admixtures in use today

- less bleed water
- more critical with low water cement ratio
- concrete can dry out and not hydrate

We need to keep the moisture in the concrete to reduce curl effects

Cool air will have a lower humidity than warm air and tend to increase the evaporation rate

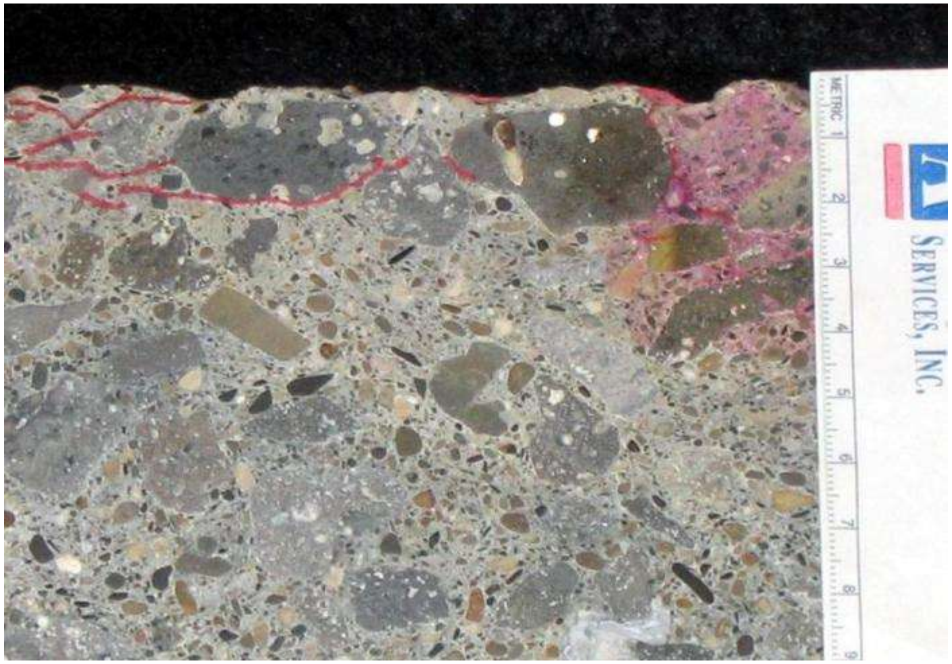
The cure system should be on-site and tested prior to concrete placement

Curing Tips

- Begin curing as soon as possible (within 30 minutes or immediately following finishing)
  - In the past, waiting until bleeding subsides was recommended
- Today most mixes have low or no bleed rates and any delay in curing is not advisable
- If the surface looks dry – it is & you are behind!
- Hairline cracks may develop which will allow water to penetrate and hurt the surface in the near future.

Concrete Durability – Improper Curing

Improper curing can affect durability. If micro cracks are allowed to form in the pavement surface, this can allow moisture to enter the pavement.

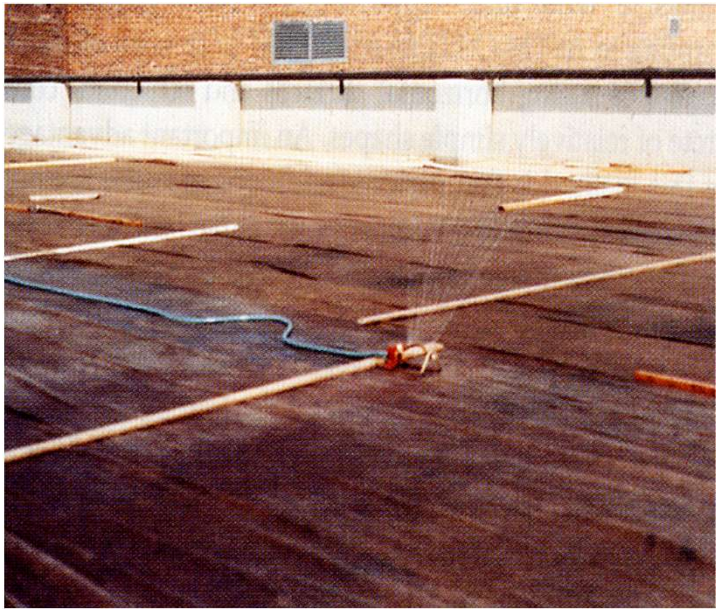


Curing Methods

Concrete can be kept moist (and in some cases at a favorable temperature) through the following curing methods:

1. Supplying additional moisture
   - ponding, immersion, spraying, fogging or wet coverings
2. Sealing in the mix water
   - membrane forming curing compounds, plastic sheeting (poly), impervious paper
3. Accelerated curing
   - live steam, heating coils or heated forms

Wet Coverings



- wet coverings may include burlap, cotton mats or other moisture retaining fabrics
- dye in burlap may cause discoloration
- keep coverings moist at all times

Polyethylene (plastic film)

- inexpensive, easy to use
- clear, white and black available
- must be at least 4 mils thick for curing purposes
- mottling or discoloration of surface may occur due to wrinkles
- can be placed over wet burlap to retain water

Curing Compounds

- most practical and widely used method
- must meet ASTM C309
- organic materials that form a skin over the surface and reduce (by ~ 80%) the rate of moisture loss
- can be white pigmented or clear
- one coat – *complete* coverage
- can be spray applied once the water sheen has dissipated - damp surface
- follow mfrs. guidelines for application rates - 150-200 ft^2/gal

Note: Curing compounds are not compatible with adhesives used with floor covering compounds. Check with the manufacturer before applying.

Sealing Compounds

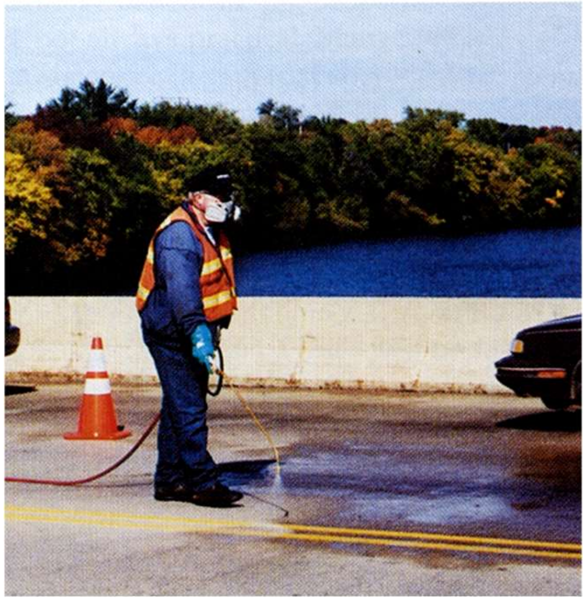
Liquids spray applied to the surface of hardened concrete to minimize the penetration of water and deicing salts.

- not applied until the concrete is at least 28 days old

- provides added protection

Sealers are classified as follows:

1. film forming compounds
   - minimal penetration
   - frequent reapplication may be necessary due to weather/traffic
2. penetrating compounds
   - penetrate approximately 1/8 inch
   - allows concrete to "breathe"



Good Curing Practice?

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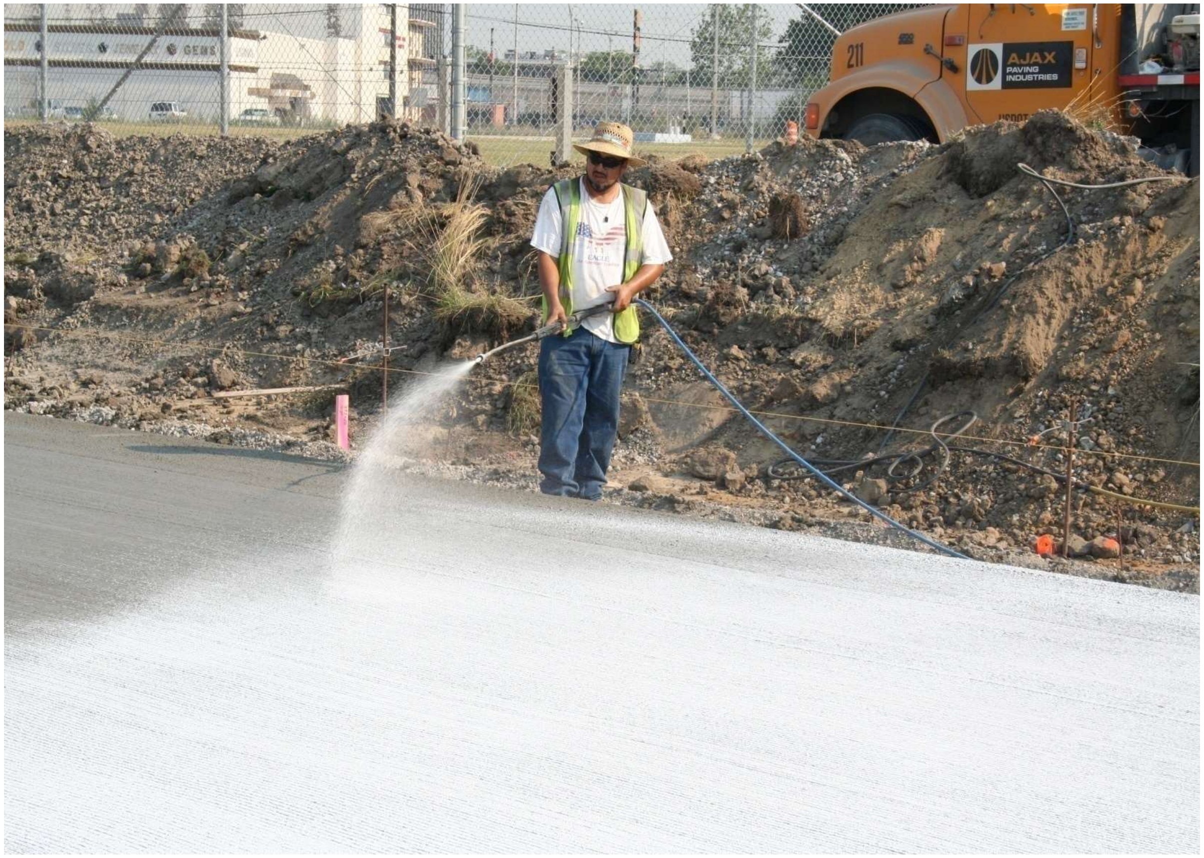
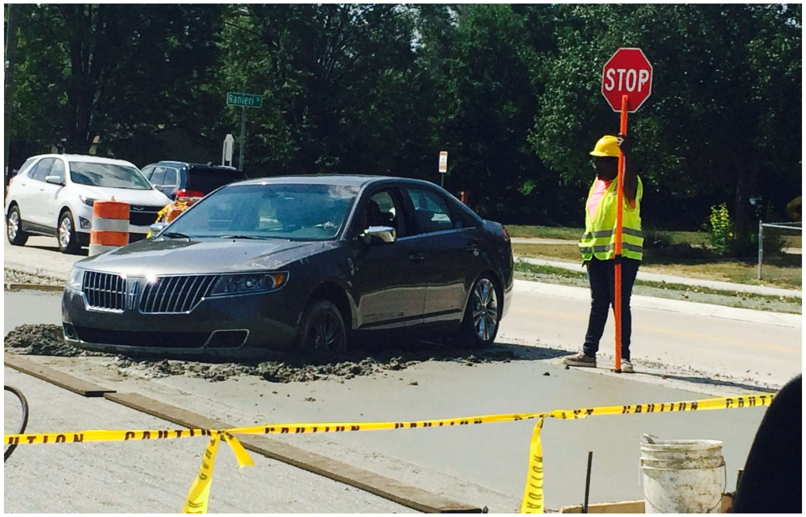


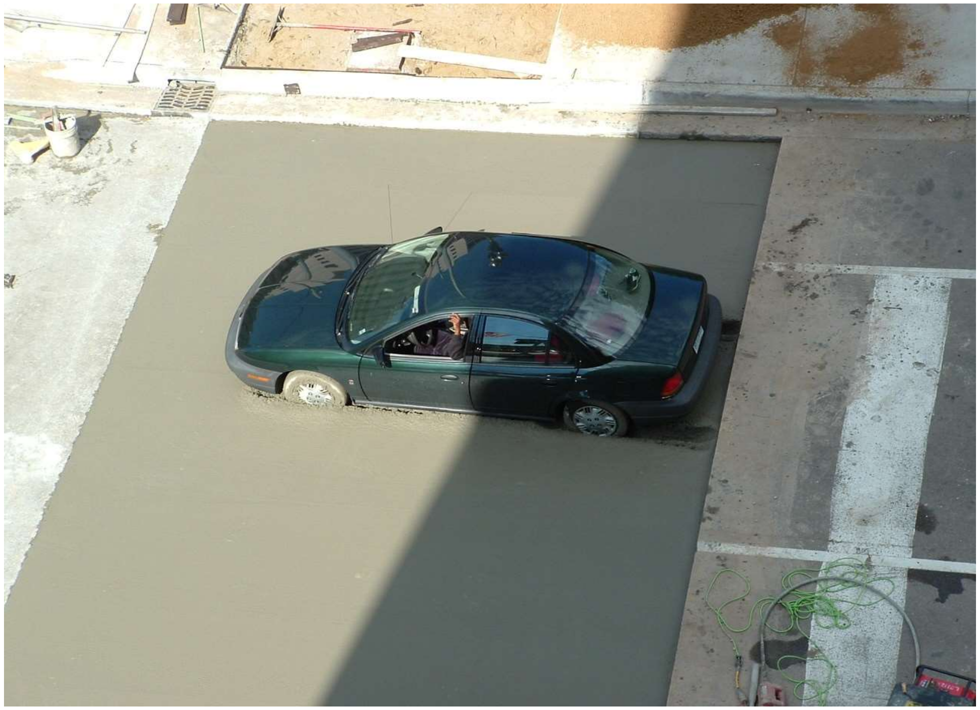
Good Curing Practice?

Good Curing Practice?

Protection From Traffic

Cured concrete may look like a good place to drive. How will you keep traffic off of the concrete for the full cure period?





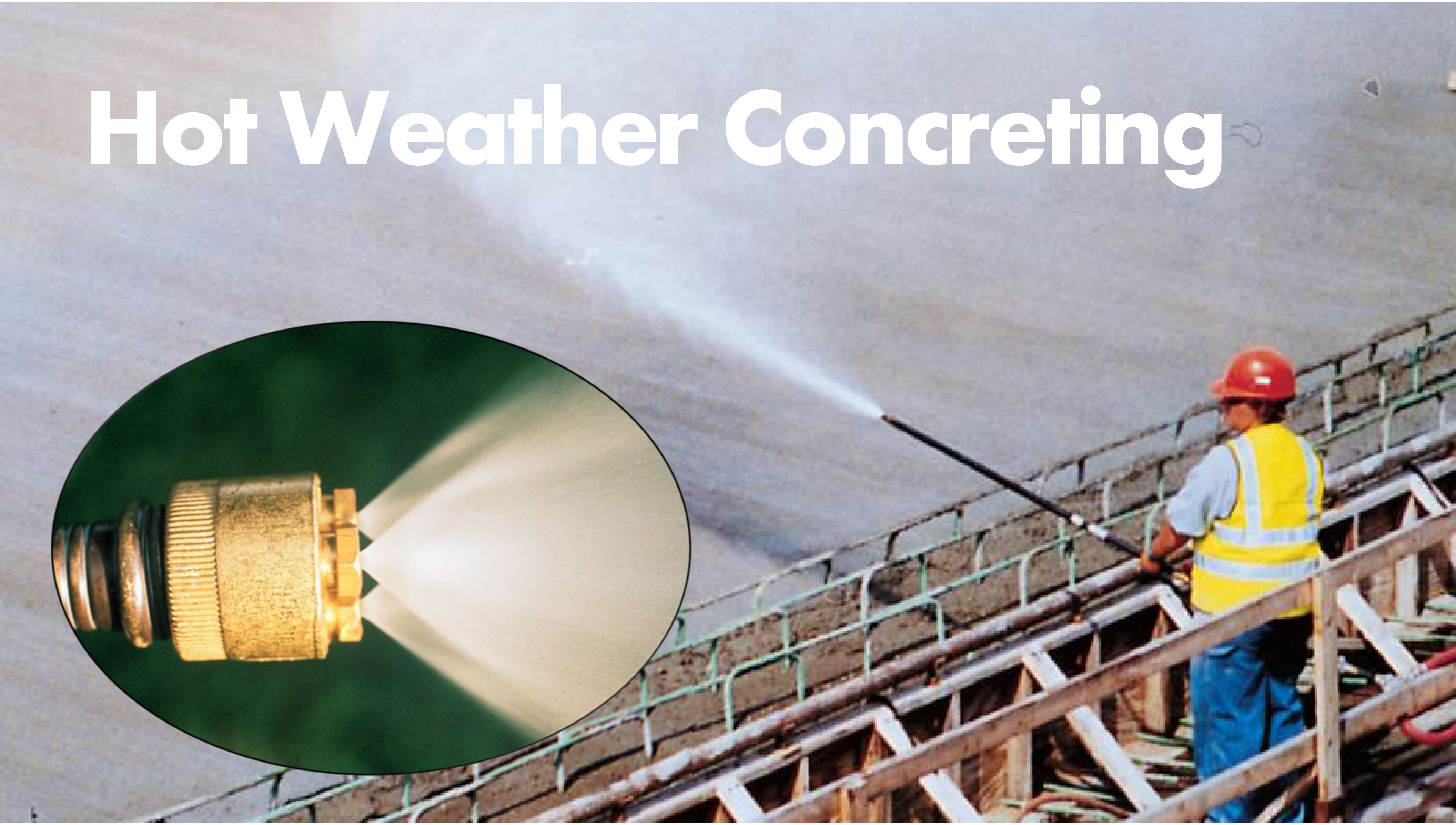
Summary

Strength and durability of concrete increases with age as long as moisture is present and temperatures remain favorable.

Lack of curing or poor curing practices can cause a loss of up to 50% of the potential strength and significantly decrease durability.

Michigan Weather

Hot Weather Concreting



Hot Weather Defined

Any combination of the following conditions that tends to impair the quality of freshly mixed or hardened concrete by accelerating the rate of moisture loss and cement hydration:

- high ambient temperature
- high concrete temperature
- low relative humidity
- high wind speed
- solar radiation

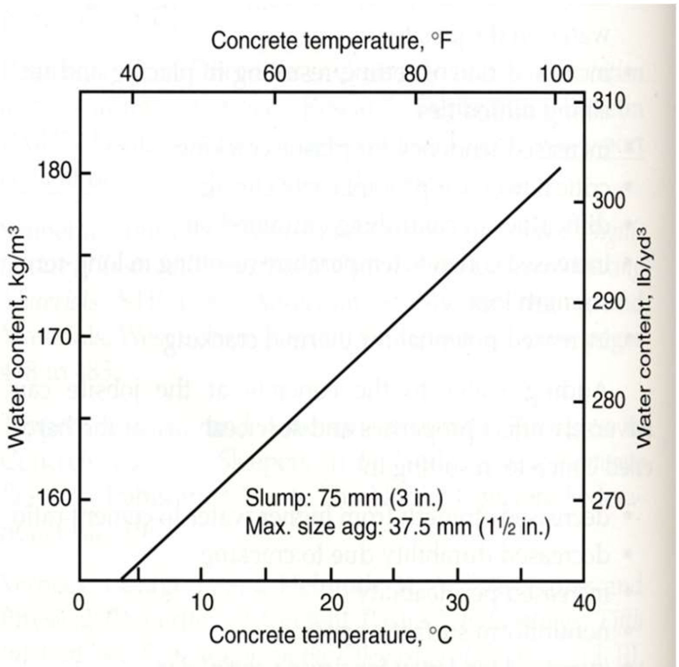
Reference: ACI 305R

Hot Weather

Hot weather conditions often contribute to the following:

1. increased water demand
2. increased concrete temperature (material temperatures)
3. accelerated slump loss (water added to offset)
4. increased rate of setting (finishing difficulties)
5. difficulties in controlling entrained air
6. increased tendency for plastic shrinkage cracking
7. increased potential for thermal cracking (heat related crack)
8. increased potential for cold joints

Temperature vs. Water Demand

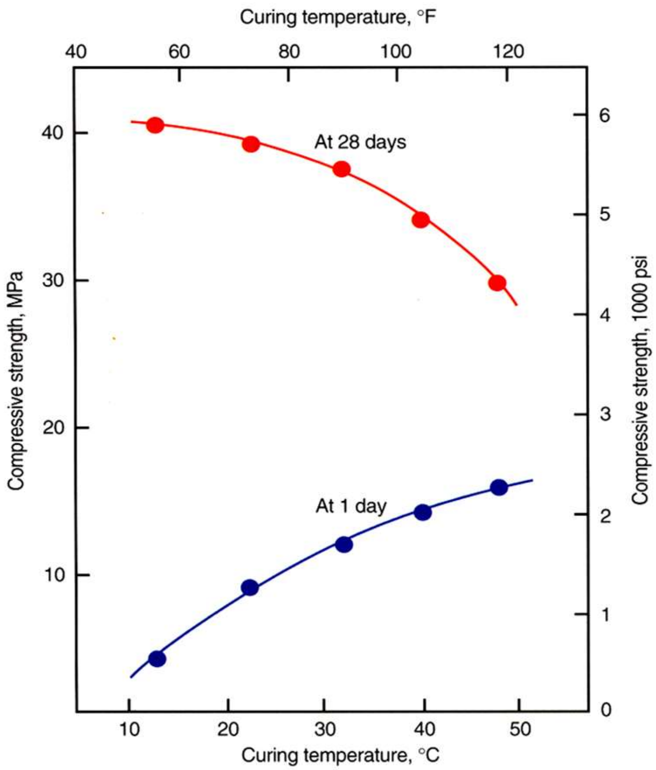


An increase in concrete temp results in an increase in water demand. From 50-100ºF, 33 lb/yd^3 of additional water is needed to maintain a constant 3 inch slump.

- this additional water results in a strength reduction of 12-15%

- other properties, such as durability, are also affected

Temperature vs. Compressive Strength



Plastic Shrinkage Cracking

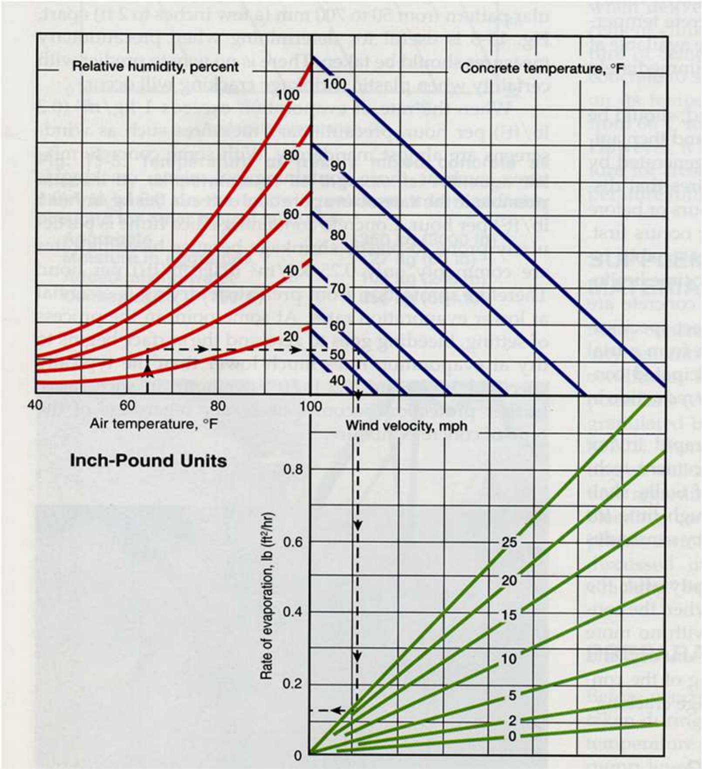
Cracks that appear in horizontal surfaces soon after placement and while the concrete is still plastic (fresh).

- results from rapid evaporation through air temperature, concrete temperature, relative humidity and wind speed

- normally associated with hot weather conditions
- can be substantially eliminated with preventive measures

- elevated decks are particularly susceptible

Evaporation Chart



When the evaporation rate exceeds 0.2 lbs/ft^2/hr precautionary measures are required to prevent plastic shrinkage cracks from forming.

- apps are available to determine the evaporation rate and whether the 0.2 lbs/ft^2/hr threshold has been exceeded

Plastic Shrinkage Cracks

One or more of the precautions noted below can minimize the formation of plastic shrinkage cracks.

1. Moisten dry, absorptive aggregates.
2. Keep aggregates and mix water cool.
3. Dampen the subgrade and forms prior to placing.
4. Erect temporary windbreaks to reduce wind velocity.
5. Erect temporary sunshades.
6. Protect concrete with temporary coverings during any appreciable delay in placement and finishing.
7. Mist or fog the slab immediately after placing and before finishing.
8. Add polypropylene fibers to the mix.
9. Spray the surface with an evaporation retarder.

Hot Weather Concreting

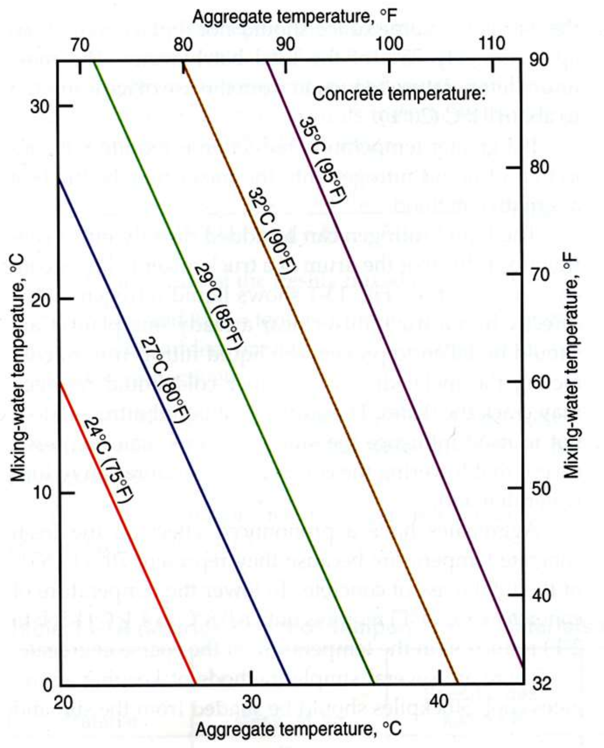
Recommendations for RMC producer and contractor:

1. Do not exceed the maximum w/c or w/cm ratio.
2. Consider the use of retarding admixtures.
3. Increase the dosage or type of water reducing admixture to offset higher water demands.
4. Replace a portion of the portland cement with slag cement or fly ash
   → hydrate at a slower rate, generate less heat.
5. Correct low air contents by increasing the AE admixture dosage.
6. Schedule evening or night placements.

Hot Weather Concreting

7. Avoid delays in delivery and placement.
8. Moisten the base before placement.
   → limits absorption, keeps temperature down
9. Keep aggregates cool by sprinkling.
10. In hot climates use crushed ice, liquid nitrogen, or take measures to cool the drum of the truck.
11. Provide sun and wind protection.
   → reduce evaporation by utilizing a fog nozzle

Batching 'Cool' Concrete Material Effects



During hot weather conditions, keep aggregates and water as cool as possible.

To lower the temperature of concrete by 1°F it takes:

1. a 1.5 - 2°F change in coarse aggregate temperature
2. a 3.5 - 4°F change in water temperature or
3. a 9°F change in cement temperature

Note: Temperature effects are dependent on the mass (weight) of the materials in the mix design.

Stockpile Conditioning

Cooling Concrete

- crushed ice is more effective than chilled water in lowering the concrete temperature
- mixing time must be long enough to melt the ice
- volume of ice should not replace more than 75% of the total batch water
- maximum temperature reduction is 20°F

Subgrade Preparation

Rain Protection

- A damp overcast day is more ideal than clear sunny day
  - Evaporation is slow in high humidity situations
- The amount of plastic required depends on how fast you are paving and how fast the concrete is setting
- In cool weather the set time decreases

Rain Recommendations

- If rain is expected to occur, cover with plastic
- Plastic will cause some minor surface marring
- Climatic conditions during rain can be conducive to good curing
- Any additional water on the surface will elevate the surface w/c ratio only if the contractor finishes the rain water into the surface. The rain water should be removed or the contractor should wait for it to drain off before refinishing
- If extremely hard rain occurs and mixes with the concrete, it may damage the top ¼-inch of pavement. Recommended correction: diamond grinding

Rain Protection

Hot Weather Summary

Hot weather conditions affect both the fresh and hardened properties of the concrete. The ready mix concrete supplier and contractor play critical roles in constructing the best possible product.

DAMAGED TO CONCRETE CAUSED BY HOT WEATHER CAN NEVER BE FULLY ALLEVIATED

CONCRETE MUST BE CURED!


Cold Weather Concreting
WIRTGEN
888-988-4400

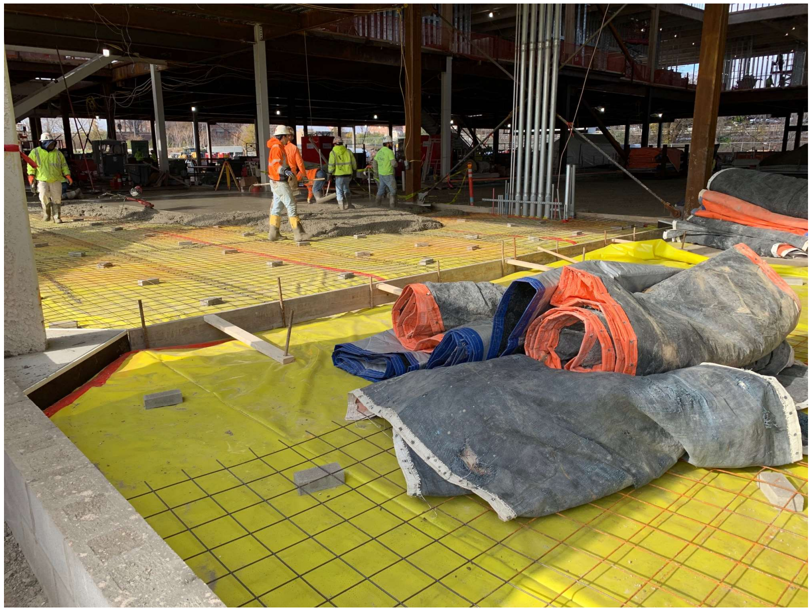
Cold Weather Defined

Cold weather conditions occur when the air temperature has fallen to, or is expected to fall below, 40ºF during the protection period.

For concreting in Michigan, cold weather practices typically begin in early November and continue until late April.

Reference: ACI 306

Cold Weather Placement



Provided that necessary precautions have been taken, concrete can be placed year round. Such precautions for cold weather construction include:

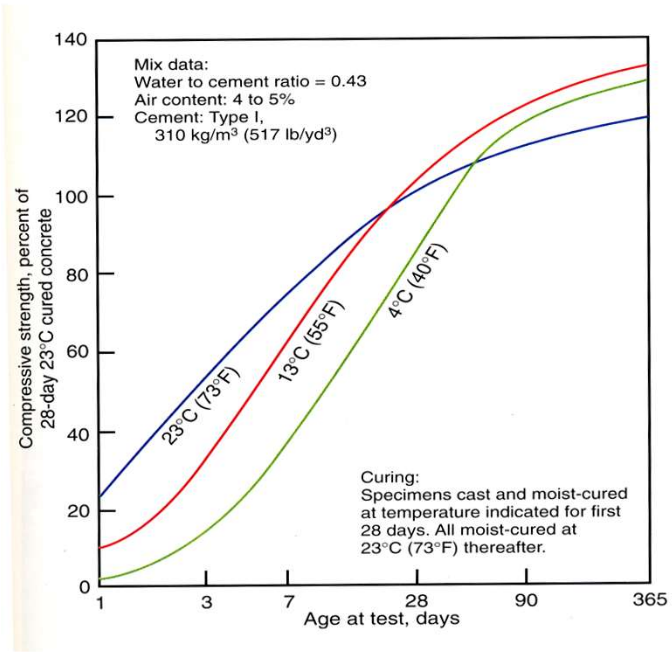
- windbreaks
- heated enclosures
- insulated forms
- insulating blankets

Temperature Effects

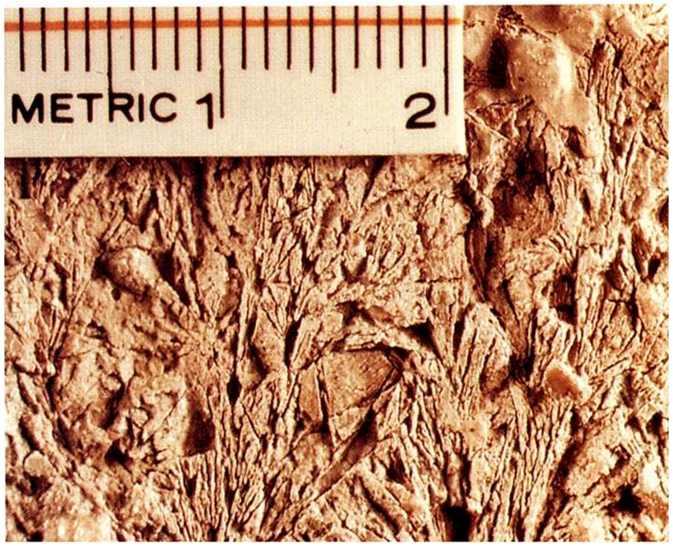
Temperature affects the rate at which hydration occurs - low temperatures slow the rate of set and strength gain.

Significant strength reductions (up to 50%) can occur if concrete freezes within a few hours of placement or before reaching a compressive strength of 500 psi.

Note: At normal temperatures, 500 psi occurs within the first 24 hours.



Frozen Concrete



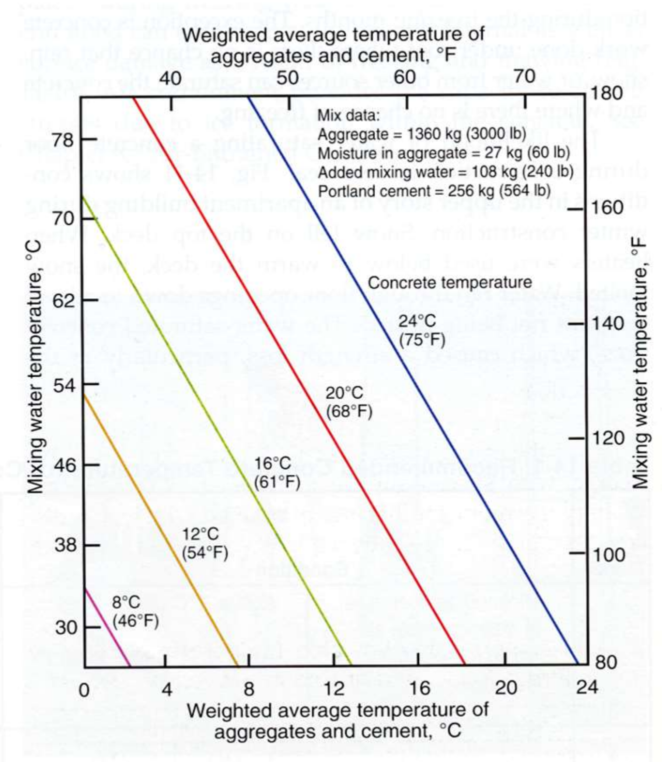
Concrete that has froze just once at an early age can be restored to **nearly** normal strengths by providing a proper curing environment. Such concrete, however, will not be as resistant to weathering nor as impermeable as concrete that had not froze.

Cold Weather Damage

Cold Weather

Responsibilities of the RMC producer:

- supply heated concrete between 60-70°F
    - heated water, heated sand or both
    - water is the easiest to heat
- maximum temperature should not exceed 90ºF per ASTM C94 and MDOT
- recommend a cold weather mix design
- frozen lumps and ice in aggregate must be thawed before using



Mix Design Recommendations

Higher early strengths and accelerated set are desirable during cold weather construction to reduce the length of time that protection is required. A cold weather mix can be designed using one, or a combination, of the following:

1. high early strength cement - Type III
2. add additional Type I - approximately 1 bag
3. add accelerating admixtures
   - either chloride or non-chloride ($$)

Note: 1. Accelerators must not be used as a substitute for proper curing and protection.

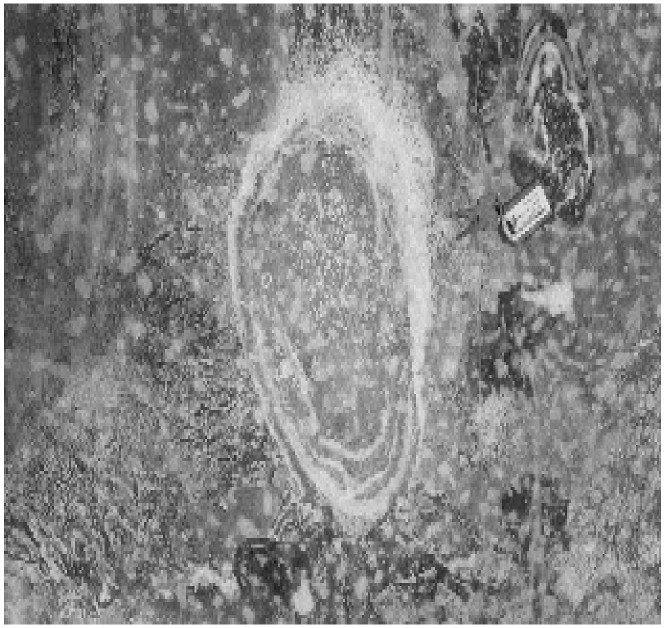
2. Consider reducing or eliminating supplementary materials.

Accelerators…Calcium Chloride

Calcium chloride is used to accelerate the set and early age strength development of concrete in cold weather. Calcium chloride accelerators may contribute to the following:

1. corrosion of reinforcing steel
2. discoloration of concrete
3. an increase in shrinkage cracking

Never add flaked calcium chloride directly into the mixer. Always dissolve in water first.



Cold Weather Placement

- The temperature of the concrete should not fall below **50ºF** from the time that it is placed until the concrete attains opening to traffic strength!
- If the concrete is delivered and placed in the 60-70ºF degree range, the internal heat generated during hydration may be sufficient to maintain the minimum temperatures if properly insulated. (Incorporate a cold weather mix design)
- Concrete should not be placed on frozen subgrade (all surfaces should be above the freezing temperature of water
    - minimum recommended temperature is 40ºF
    - steam, cover w/insulation material, hydronic heaters
- Remove all frost before placing the concrete and recompact thawed soil

Cold Weather Protection

After placement cure and protect the concrete

- Heat and moisture are retained by covering concrete with:
  1. insulating blankets or
  2. straw/hay that is typically covered by polyethylene.
     - i. corners and edges are most vulnerable to freezing
- The material selected for providing cold weather protection must be moisture-proof and able to withstand exposure to the weather

NOTE: Cylinders & Beams **MUST** be protected from the elements as well.

Cold Weather Protection

- Cold weather protection should be placed as soon as it will not mar the surface of the pavement and protect the full exposed surface for the entire time it takes to achieve opening to traffic strength
  - NOTE: The insulating material can be removed for cutting of the joints in the pavement, but should be replaced immediately. Make sure that the cover is secured in place!
- At the end of the protection period, concrete should be cooled gradually to ambient temperatures to reduce crack-inducing differential strains (thermal shock) between the interior and exterior of the of the pavement.

Protection… Plastic Sheeting

Protection…Straw/Hay

A minimum of 1 ft. is required to provide the necessary insulating (R) value. Straw or hay must be covered with visqueen (poly) to securely hold it in place.

Caution: At temperatures below 40°F hydration proceeds very slowly.

Protection…Insulating Blankets

R-Value Comparisons – per inch

Material	Density kg/m³ (lb/ft³)	Thermal resistance, *R*, for 10-mm (1-in.) thickness of material,* $(m^2 \cdot K)/W$ $([°F \cdot hr \cdot ft^2]/Btu)$
Board and slabs		
Expanded polyurethane	24 (1.5)	0.437 (6.25)
Expanded polystyrene, extruded smooth-silk surface	29 to 56 (1.8 to 3.5)	0.347 (5.0)
Expasnded polystyrene, extruded cut-cell surface	29 (1.8)	0.277 (4.0)
Glass fiber, organic bonded	64 to 144 (4 to 9)	0.277 (4.0)
Expanded polystyrene, molded beads	16 (1)	0.247 (3.85)
Mineral fiber with resin binder	240 (15)	0.239 (3.45)
Mineral fiberboard, wet felted	256 to 272 (16 to 17)	0.204 (2.94)
Vegetable fiberboard sheathing	288 (18)	0.182 (2.64)
Cellular glass	136 (8.5)	0.201 (2.86)
Laminated paperboard	480 (30)	0.139 (2.00)
Particle board (low density)	590 (37)	0.128 (1.85)
Plywood	545 (34)	0.087 (1.24)
Loose fill		
Wood fiber, soft woods	32 to 56 (2.0 to 3.5)	0.231 (3.33)
Perlite (expanded)	80 to 128 (5.0 to 8.0)	0.187 (2.70)
Vermiculite (exfoliated)	64 to 96 (4.0 to 6.0)	0.157 (2.27)
Vermiculite (exfoliated)	112 to 131 (7.0 to 8.2)	0.148 (2.13)
Sawdust or shavings	128 to 240 (8.0 to 15.0)	0.154 (2.22)

R-Value Comparisons – per inch *(continued)*

Material	Density kg/m³ (lb/ft³)	Thermal resistance, *R*, for 10-mm (1-in.) thickness of material,* $(m^2 \cdot K)/W$ $([°F \cdot hr \cdot ft^2]/Btu)$
Mineral fiber blanket, fibrous form (rock, slag, or glass) 5 to 32 kg/m^3 (0.3 to 2 lb/ft^3)	50 to 70 (2 to 2.75) 75 to 85 (3 to 3.5) 90 to 165 (5.5 to 6.5)	1.23 (7) 1.90 (11) 3.34 (19)
Mineral fiber loose fill (rock, slag, or glass) 10 to 32 kg/m^3 (0.6 to 2 lb/ft^3)	95 to 125 (3.75 to 5) 165 to 220 (6.5 to 8.75) 190 to 250 (7.5 to 10) 260 to 350 (10.25 to 13.75)	1.90 (11) 3.34 (19) 3.87 (22) 5.28 (30)

* Values are from *ASHRAE Handbook of Fundamentals*, American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc., New York, 1977 and 1981.
R values are the reciprocal of U values (conductivity).

Heated Enclosures

Heated enclosures are expensive to construct and operate but allows for construction to continue during cold weather conditions.

Construction Heaters

The two types of heaters used during cold-weather concrete construction include:

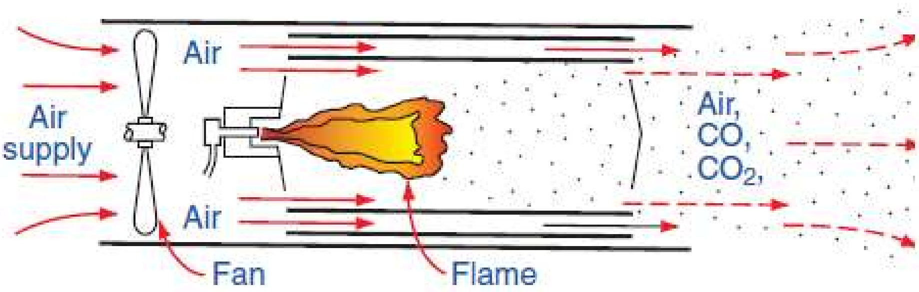
1. Direct-fired (unvented)
2. Indirect-fired (vented)

Carbon dioxide (CO_2) in the exhaust of heaters must be vented to the outside and not allowed to react with a fresh concrete surface or carbonation will occur.

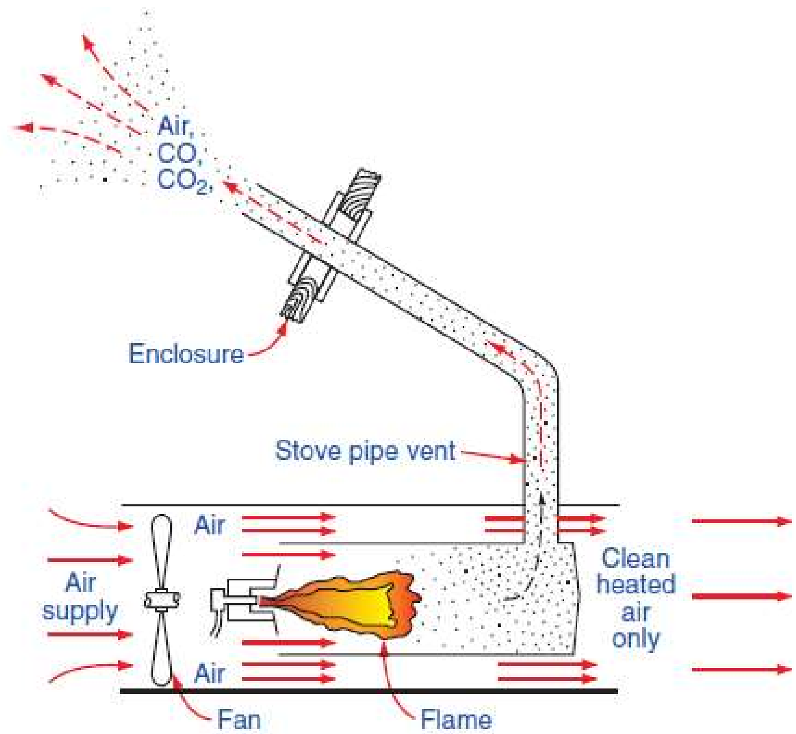
- carbon monoxide (CO), another by-product of combustion, is not a problem for concrete but poses a potentially serious health risk to workers

Direct vs. Indirect Fired Heaters

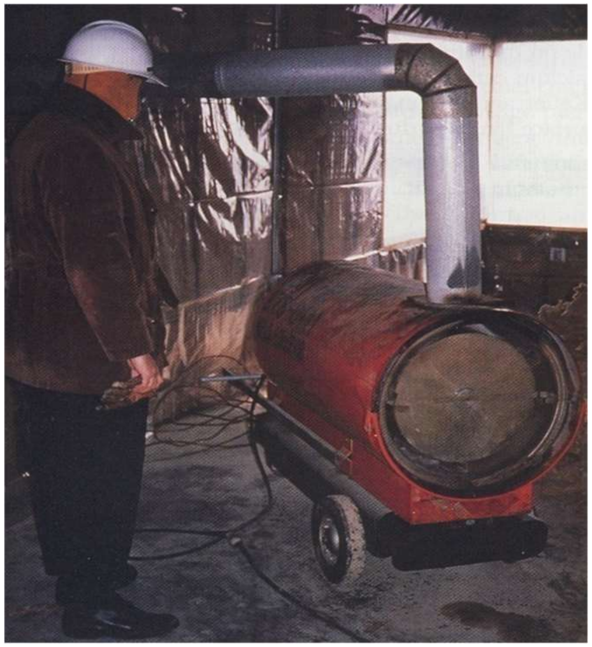
Direct Fired



Indirect Fired



Indirect Fired Heater



Carbonation – Mild/Severe

Heated Enclosure Solution

Avoid the use of direct fired (unvented) heaters.

If direct fired heaters are used:

- avoid using older, less efficient heaters
- provide good air exchange and circulation
- minimize the period of exposure
- if carbonation occurs, clean/grind surface and apply a chemical hardener (densifier)

Hydronic Heating Systems

Cold Weather Cylinder Protection

For specified compressive strengths less than 6000 psi, initial curing requires cylinders be stored at a temperature between 60-80°F for a period not exceeding 48 hrs.

- construct your own insulated curing box or purchase a commercially sold unit

Cylinder protection - Unacceptable

QUESTIONS??